END-EFFECTOR FOR FAST WIRE CUTTING AND CRIMPING ON A 4-DOF PARALLEL ROBOT

A.Tasora, M.Silvestri
Università degli Studi di Parma
Parma, Italy,
tasora@ied.unipr.it, silve@ied.unipr.it

Abstract

This article describes the development of compact and efficient tools exploited by a 4-DOF robot during an automated process aimed at building heating coils. Resistive wires must be cut and crimped into small connectors at a fast pace, with extreme repeatability and reliability. We designed two special tools for the end effector of a parallel-kinematic robotic device. Wire cutting has been obtained by means of two custom blades. Crimping the resistive wire into connectors required the development of small, yet stiff, pneumatic crimping pliers endorsing a novel kinematic scheme. The robot successfully performed the high-speed tests, showing the high performance of the tools mounted on a multifunctional end-effector.

1. INTRODUCTION

Wire coils are widespread components used in hair dryers, toasters and similar devices. Automated assembly processes for these products may be difficult because coils are made of thin resistive wires wrapped around oddly shaped insulating mica plates. Metallic connectors for the ends of the coils, as well as thermal emergency switches, are mounted on these mica plates.

Given the small size of these parts, their flexibility and the uncertainty of their position, the task of cutting the resistive wires and the crimping of their ends into miniaturized connectors are critical phases of the automated assembly process.

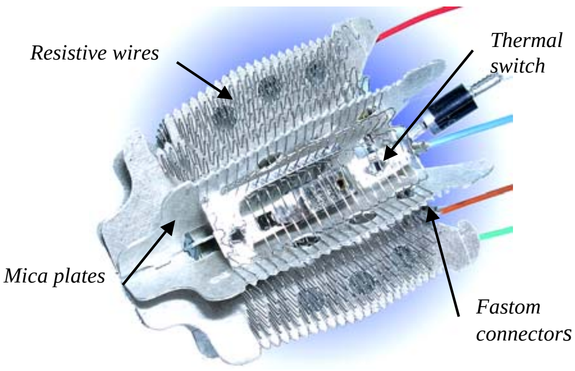

Fig.1 : Heat coil to be assembled

In this paper we present a multi-functional tool for a robot which assists the assembly line of a complex heat coil for hi-end hairdryers, whose design exploits a triple-wire, triple-circuit wiring wrapped into a patented coaxial configuration supported by 12 interconnected mica plates (see Fig. 1).

The manual assembly process was lengthy and not precise, so a full-digital-authority automation process has been studied and implemented, requiring no human supervision. A novel parallel-kinematics robot represents the main device in the new automated assembly line, and it must perform three main tasks.

First, it must be able to pick mica plates of different sizes from different dispensers, and mount them into the

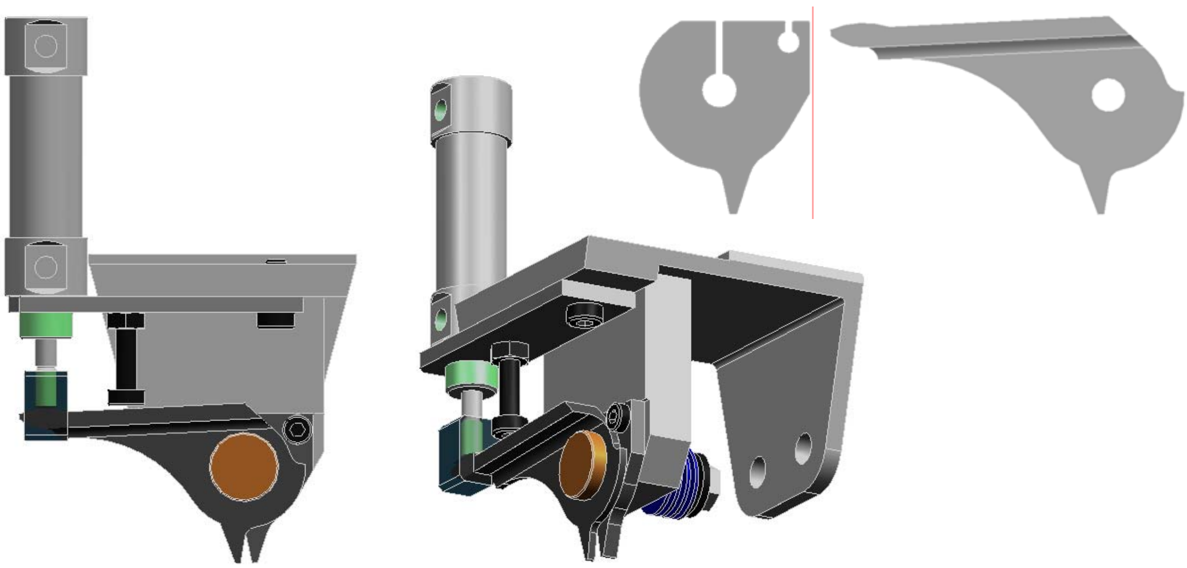

Fig.2: Wire cutter. Up right, closeup of EDM cutting path for scissor blades.

rotating shaft which will wrap the wires.

Second, it must cut the wires at the beginning and at the end of the cycle, in six different positions.

Third, it must crimp the wire ends into the four connectors, in four different positions.

Since the parts are very small, no positioning errors can be tolerated. Meanwhile, the motion of the robot must be fast enough to allow high paces in coil production. For these reasons we designed a custom parallel-kinematics robot, called *GRANIT* (see Fig. 3), which has some special features. In detail, because of the parallel kinematics architecture [1], the robot is very stiff and precise: we experienced that repeatability is as good as 0.01mm. Such robot has 4 degrees of freedom, hence acting like a *SCARA*, but exploiting extreme stiffness, low inertias and accelerations over 30 m/s^2.

In order to exploit the high dynamical properties of this robot, the end effector had to be as light as possible: this requirement enforces a constraint on many design solutions. Also, the end effector had to be very compact in size, mostly because the working volume is cluttered by many devices that are not illustrated in this paper.

Fig. 3: The *GRANIT* parallel-kinematics robot

2. WIRE CUTTING

Resistive wires are usually made of special austenitic alloys, most often NiCr or NiCrFe alloys, sometimes called *Nichrome alloys*. In our case, we took into consideration different wires with different chemical composition, because various models of heat coils are under production, depending on 110V/240V operating mode or total power (up to 1700W). Depending on the model, the wire diameter can range from *D*=0.20mm to *D*=0.25mm, while the material can be a Nichrome alloy like the *Nicrothal™ N40* (35%Ni, 20%Cr, Fe balance) or similar.

Despite pneumatic nippers are already available on the market, even with flanges for easy mounting on robot effectors, we decided not to use this solution mostly because pneumatic pliers are mainly targeted at cutting small plastic parts or soft metals (copper wires), while Nichrome alloys can be quite hard. Also, nippers do not guarantee that the cut always happens: if the blades of the nippers are worn or dented, the wire will be simply trapped in the closing nipper, and this will cause

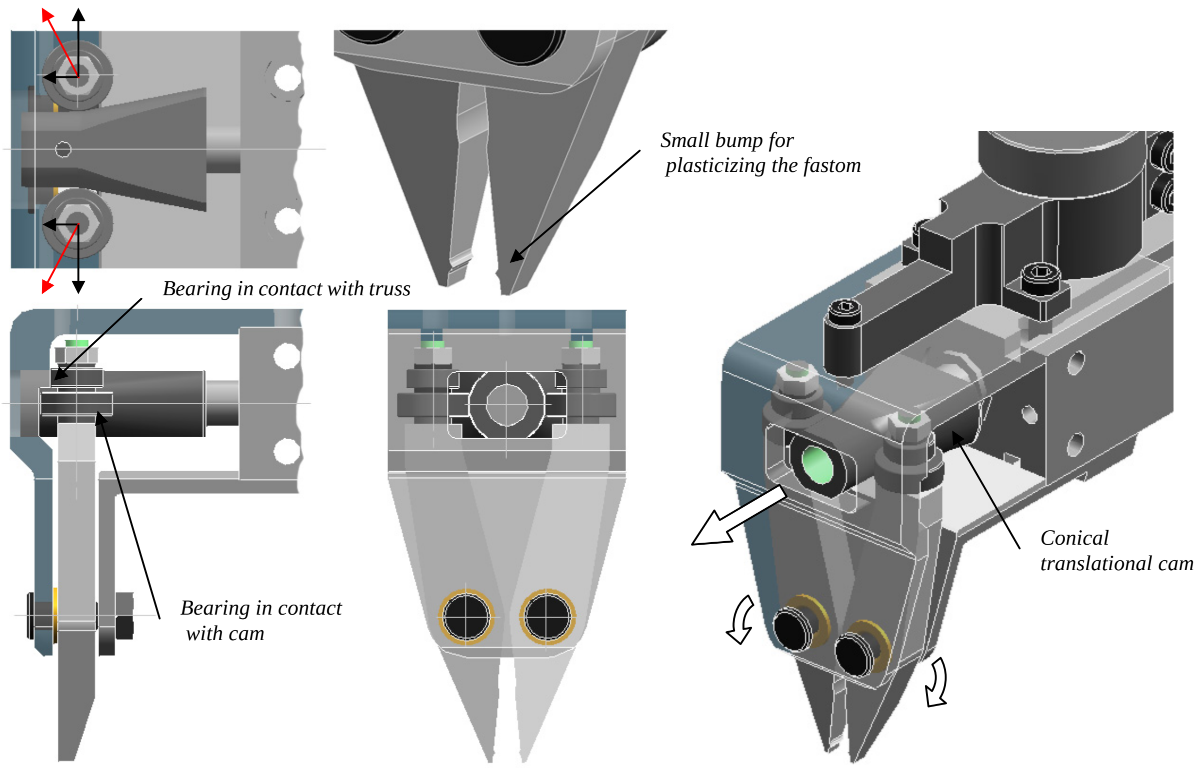

Fig.4: The pneumatic plier for wire crimping. It also acts as a truss for the multifunctional end-effector.

unpredictable entanglements. Last reason is that commercial nippers are too heavy to be mounted on our end-effector, which moves on high-speed trajectories.

Therefore we developed a solution based on a compact scissor-like mechanism, where a sensor can detect if scissor blades have been completely closed. Most important, our scissor blades have been built with a design which allows easy dismounting for periodic maintenance: using a grinding machine to remove a 0.1÷0.05mm flat layer from the contact faces, worn edges can be quickly repaired.

To perform a correct dimensioning of the scissor, we built a test bed which provided experimental results for the cutting force. For a wire with diameter D and ultimate tensile strength σ_s the normal force $F_\perp$ to be applied to the blade for wire cutting should be:

$$F_\perp \geq K \frac{\pi D^2 \sigma_s}{4} \qquad (1)$$

where we found that K is in the 0.55÷0.7 range and σ_s=675 N/mm^2÷800N/mm^2 for most NiCr or NiCrFe alloys. When K=0.58, equation (1) leads to the theoretical values which can be obtained by applying the straightforward Von Mises-Henky failure theory for pure τ_{xy} shear of a cylinder [3].

From these results we designed a very compact scissor mechanism, as depicted in Fig.2. Interesting enough, we discovered that the optimal cutting angle of the blades is about 10°.

To avoid premature wear of blades we choose pre-hardened high-speed-steel (cobalt-molybdenum DIN HS2-9-1-8) or pre-hardened cold-cut steel (K110, DIN X115CrMoV12-1).. Since these hardened alloys cannot be cold-machined (hardness HRC>65, HV>800) the blades have been cut using *wire electro-discharge-machining* (EDM).

3. WIRE CRIMPING

Crimping of resistive wires into miniaturized connectors is a matter of squeezing a thin “C” shaped strip of metal around the end portion of the wire. The metallic connectors are usually made of tin-plated steel foils, with thickness up to 0.8mm.

Previously, the manual assembly cycle used commercial hand-operated pneumatic pliers to perform this task. However, a conservative approach for the estimation of the crimping force lead to many structural failures in pliers, as can be seen in Fig. 5.

Fig.5: Structural failure of old pliers

For this reason we built an experimental device which helped us to understand the lowest admissible force for the crimping operation: we obtained that a safe and reliable crimping could be obtained with a force of F_c=500N. On the basis of these experimental results we designed a pneumatic crimping tool which can exert a maximum force of 1000N when operating at 6bar. Thank to a pressure regulator it can obtain lower forces.

The crimping tool has a novel kinematic scheme (see Fig.4) exploiting a 90° turning of force transmission, starting from a compact horizontal cylinder, going through a conical cam-rocker mechanism, then ending with the rotation of the vertical pliers. This was mandatory because the vertical space was very limited. In sake of the least stress of structures, there are two small auxiliary bearings which avoid that horizontal forces coming from the conical cam may bend the pliers forward (see Fig.4, left).

Because of constraints on sizes and masses, the small pliers (maraging steel ISO X2NiCrMo18-9-5) have been optimised both via experiments and FEM software.

5. CONCLUSIONS

We designed, built and tested a multifunctional end effector for a 4-DOF parallel-kinematics robot. Special tools have been studied for the tasks of wire cutting and wire crimping, in aim of the lowest mass, smallest size and highest reliability. By means of experimental tests we obtained data about the correct dimensioning of the cutter and the crimping pliers. The robot successfully performed high-speed tests, demonstrating the good performances of the tools.

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References

[1] Righettini,P., Tasora,A., Giberti,H.: “Mechatronic design of a 3-DOF parallel translational manipulator”, *RAAD 2002*, 11th Workshop on Robotics in Alpe-Adria-Danube Region, 30 June - 2 July 2002, Hungary

[2] Righettini,P., Tasora,A., Giberti,H.: “Simulation of Pneumo-Mechanical System in a Multibody Environment”, *VENTIL*, ISSN 1318-7279, pp.79-83, June 2003, Slovenia

[3] Beer,F.P., Johnston, E.R., DeWolf, J.: Mechanics of Solids, Ed. McGraw Hill (3rd edition)

[4] URL: *http://www.kanthal.com*, alloys datasheet.

Alessandro Tasora graduated from the Politecnico di Milano institute, and currently teaches robotics at the University of Parma. His interests include CAD, multibody, tribology, computational geometry, numerical methods and computational dynamics.